

Electrification in Winter Storms and the Analysis of Thunderstorm Overflight Data. NASA Grant NAG-066.

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INTRODUCTION.

Until recently, electrification in winter storms has been observed only casually. Electrical activity is sparse, the lightning flashes are few and far between, and the number of winter thunderstorms is only a small fraction of those that occur in summer. Consequently, most lightning investigators have spent their winters analyzing summer data. The pioneering work of Takeuti et al.(1977) in Japan served to focus the attention of the international community on the existence of anomalous electrical effects associated with winter storms. In particular, the existence of positive return strokes of magnitude as large as 310 Coulombs was a new observation difficult to explain, especially since the Hokuriku winter storm clouds seldom exceeded 4-5 km in height (how do you fit so much charge into such a small volume of cloud?). Positive lightning strokes were also found to be the dominant polarity of strokes in the Hokuriku winter storms (Brook, et al., 1981).

The emergence of 24 hr operational lightning detection networks has led to the finding that positive lightning strokes, although still much fewer in number than the 'normal' negative strokes, are also present in summer storms. Recent papers such as Goodman, et al.(1988) point up the importance of understanding the meteorological conditions which lead to a dominance of one polarity of stroke over another; in the paper cited the sudden appearance of positive strokes at the end of a storm appeared to presage the end-of-storm downdraft and subsidence leading to downburst activity. It is beginning to appear that positive strokes may be important meteorological indicators.

SIGNIFICANT ACCOMPLISHMENTS OF THE PAST YEAR.

1. DO THE NETWORK BLACK BOXES TELL THE TRUTH? Our initial effort on this grant was a study to verify that the "Black Boxes" used in the lightning networks to detect both negative and positive strokes to ground were telling the truth. After all, for more than 60 years scientists believed that ONLY negative charge was lowered to earth in return strokes.

We made waveform and polarity determinations with our own instrument operating side by side with the SUNYA LLP equipment. We found that, for lightning flashes within about 600 km of the SUNYA equipment the boxes gave the correct identification of stroke polarity. Only very occasionally did we have reason to believe that a pulse from an intracloud discharge was counted as a positive stroke. We were surprised to find, however, that for strokes occurring beyond about 700 km from the equipment, the polarity was generally wrong. Suffice it to say that for large distances over land the ground wave is often severely attenuated; the first ionospheric reflection suffers much less attenuation and arrives at the station with inverted polarity! This and other work related to determining stroke polarity from waveform measurements is discussed in the paper Brook et al., 1989.

2. SLOW TAILS CAN BE USED TO DETERMINE THE POLARITY OF DISTANT LIGHTNING.

An outgrowth of this initial work on radiated lightning waveforms was the discovery that it is possible to determine the polarity of distant lightning correctly if the lightning stroke has a low frequency component, such as might be present in the long continuing-current strokes. The cutoff frequency for electromagnetic waves propagating in the earth-ionosphere waveguide is ~2000-3000 Hz depending upon ionospheric height. If the stroke has low frequency components, then the waveform as seen at distances of 500 km or greater from the source shows the attenuated VLF radiation components followed by a 'slow tail' propagating in the earth-ionosphere waveguide. We verified

that, for over one hundred cases, the polarity of the slow tail is the same as the original stroke polarity at the source. This result has important practical application since it is specific as to the frequency content of the stroke. Over 95% of the forest fires started by lightning are due to continuing-current strokes. An application for a patent is in progress (NASA Case MFS-26102-1).

3. LIGHTNING INITIATION IN WINTER vs. SUMMER STORMS. The most important results achieved to date relate to the electric field strength in clouds for winter vs. summer storms. We have been studying the initial breakdown phase of lightning in both strokes to ground and in intracloud discharges. What we find is little or no difference in the initial pulse activity associated with intracloud breakdown, but there is a striking difference between negative stepped leader development in winter vs. summer storms. Specifically, negative leaders in winter storms have a higher propagation velocity, are much shorter in duration, and exhibit E-field amplitudes which are often as large as if not larger than the return strokes which they precede. We interpret these characteristics along with other evidence to indicate that electric fields in winter clouds are considerably greater than they are in summer clouds. Since the electric energy stored in a cloud is proportional to the square of the electric field, we have here a possible explanation for a number of 'anomalous' features of winter storms.

Electric breakdown in clouds is determined not only by atmospheric pressure, but also by the presence of water drops under electric stress. At high values of electric field, water drops distort to ellipsoidal shape, and for high enough field values will go into corona and provide a copious source of ions to initiate a discharge (G.I. Taylor, 1965). Initiation will occur for electric field values well below the normal breakdown potential gradient of air. Thus, for dry air at NTP the breakdown potential gradient is $\sim 30,000$ V/cm, but in the presence of liquid water drops it will fall to values as low as 3000 to 10,000 V/cm, depending upon the radius of the drops. The presence of water drops in an electrified cloud can be thought of as providing an upper limit to the value of the local electric field.

Meteorological soundings taken at about the time of our winter storm data indicate that at the 4-6 km level (-10 to -20 deg C environment) the vapor pressure was close to saturation over an ice surface, indicating a dominance of solid rather than liquid form precipitation. We believe that the absence of large numbers of liquid water drops of size significant for lowering the breakdown potential gradient of air is the major factor in allowing the electric field to build up (whatever the mechanism) to values greater than those found in summer storms. The higher energy density achievable in winter storms would increase the probability that aircraft will trigger lightning upon penetration. It was the unusually high lightning related hazard provided by the shallow winter clouds off the sea of Japan which initially motivated the Japanese scientists to investigate the winter storms. A paper on the winter storms is now in an advanced stage of preparation.

4. INSTRUMENT DEVELOPMENT. We continue to upgrade our sensors for the measurement of electric field signals associated with lightning. We completely redesigned the Slow Antenna system to cure two problems: 1) the charge left on the flat plate antenna from blowing snow has been minimized by the use of an inverted 'salad bowl' housing which contains the 18" diameter plate and all the electronics; 2) Reduction of the input bias current to about .5 picoamperes has allowed us to use resistors as large as 10^{12} ohms without suffering prohibitive offsets. The 10 second time constant and the high sensitivity achieved allowed us to measure electrostatic field changes from as far away as 125 km. The wideband (.1 Hz to 2MHz) Slow Antenna sensor with the 12 bit 2MS/s digitizer is useful in studying simultaneously the radiation as well as the electrostatic fields of lightning.

5. OTHER ANALYSES IN PROGRESS. a) We are analysing lightning flash

records from storms between 40 and 125 km from the sensor. The ratio of electrostatic field, which varies as $\sim 1/R^3$, to the radiation field which varies as $1/R$, for each stroke in a multiple stroke flash is of interest as a possible indicator of the distance R from the receiver. b) An interesting aspect of the initiation process involves the physical processes driving the stepped leader. In particular, the "turn on" and "turn off" aspects of the individual stepped leader pulses do not seem to fit accepted mechanisms. We are sorting through our summer storm lightning data to find several more good leaders from close storms.

FOCUS OF CURRENT RESEARCH AND PLANS FOR NEXT YEAR.

Our research objectives remain focused on the electrical aspects of winter storms, how they differ electrically from summer storms, and the association of changes in the cloud physical and dynamical environment with the onset or cessation of positive lightning strokes. We have been working on the hardware components for a second (and possibly a third) measurement station. Plans are to set up three stations, one at Albany, N.Y., one at Huntsville, and another at Socorro or Norman, Ok. We also plan to expand the data acquisition to two channels: 1) The regular E-field channel, and 2) an RF channel at ~ 250 MHz. The logarithmic receiver channel will provide us with complementary information regarding the lightning stroke initiation process.

Immediate plans for this coming year involve participation in the CAPE program at KSC during July and August. This work would also include cooperative observations with Dr. Vincent Idone on the electrical and optical properties of initial leaders during the ongoing lightning triggered program at KSC. Additional participation is planned with Dr. Richard Blakeslee at Huntsville to provide improved electric field instrumentation for the ER-2. We have also been in touch with the Marshall group regarding the implementation of a lightning monitoring station which would be used in conjunction with radar precipitation estimates for possible algorithm development relating lightning to precipitation as part of the ground truth activities of the TRMM program.

Multiple station measurements of winter storms are planned for this winter (probably late November through early January) with one station at Albany and the other at Huntsville. We are particularly interested in measuring the electrostatic field change involving continuing current strokes close to one station with the second distant station receiving the radiation waveform. This work will hopefully lead to identification of the source of the slow tail waveform. Since many of the large positive strokes in winter storms are accompanied by large continuing currents, we should be able to acquire the necessary data simultaneously at the two stations. We shall also try to arrange for recorded radar records of the winter storms along with the soundings in order to test our hypothesis that the fields within winter storm clouds are stronger than in summer clouds because of the nature of the precipitation mix.

PUBLICATIONS

1. Brook, M., Ron W. Henderson and Richard B. Pyle, Positive Lightning Strokes to Ground, *J. Geophys. Res.*, **94**, 13295-13,303 (1989)
- In Preparation: Electrification in Winter Storms (Paper presented at Fall AGU meeting, San Francisco, Dec. 1989)
- Ratios of Radiation Amplitude to Electrostatic Field Change in Multiple Stroke Lightning Flashes (Paper presented at Fall AGU meeting, San Francisco, Dec. 1990)

